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ST. PETER AND ST. PAUL'S ROCKS (EQUATORIAL ATLANTIC) AND THE SURROUNDING SEA FLOOR

by

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Abstract

This report gives details on the sampling locations, rock types recovered and bathymetry and morphology of the Islets of St. Paul's Rocks (equatorial Atlantic) and the surrounding sea floor. This work was done during Cruise 35 of R/V Chain, 1963 and Cruise 20 of R/V Atlantis II, 1965.

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FIGURE CAPTIONS

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St. Paul's Rocks and Surrounding Sea Floor

(1) Introduction:

The Rochedos São Pedro e São Paulo, commonly known as St. Paul's Rocks, are a small group of barren islets and rocks located approximately 80 Km north of the equator and close to the axis of the mid-Atlantic Ridge. They appear to be closely allied with the transverse faulting of the Ridge typically found in the Equatorial Atlantic (Figure 1). Their unique character in respect of oceanic islands, namely that they are composed of ultramafic rocks and not volcanic, has long been recognized (Darwin, 1900). The petrology of some of the rock types from the islets have been reported (Renard, 1882, 1879; Washington, 1930a, b; Tilley, 1947, 1966).

The discovery of, and a summary of earlier visits to the Rocks, along with a description of the islets have been reported by Tressler et al., (1956). Since the Tressler report, the Rocks have been the subject of investigation by HMS Owen in 1960 (Wiseman, 1966); the German vessel Meteor in 1966, details of sampling, if any, are unknown; and the RV Pillsbury in 1968 (Bonatti, 1968).

The St. Paul's Rocks and surrounding sea-floor have also been investigated by the Woods Hole Oceanographic Institution vessels RV Chain in 1963, and RV Atlantis II in 1966. Preliminary descriptions of some of the rocks from these two cruises have been reported (Melson et al., 1967a,b, 1972, 1973; Thompson et al., 1968; Thompson, 1972). A more complete description of the findings of these two cruises form the basis of this report.

(2) Sampling and Data Collection:

a. St. Paul's Islets:

For this report, the nomenclature of the individual islets is as given by Tressler et al., (1956) and shown in Figure 2.

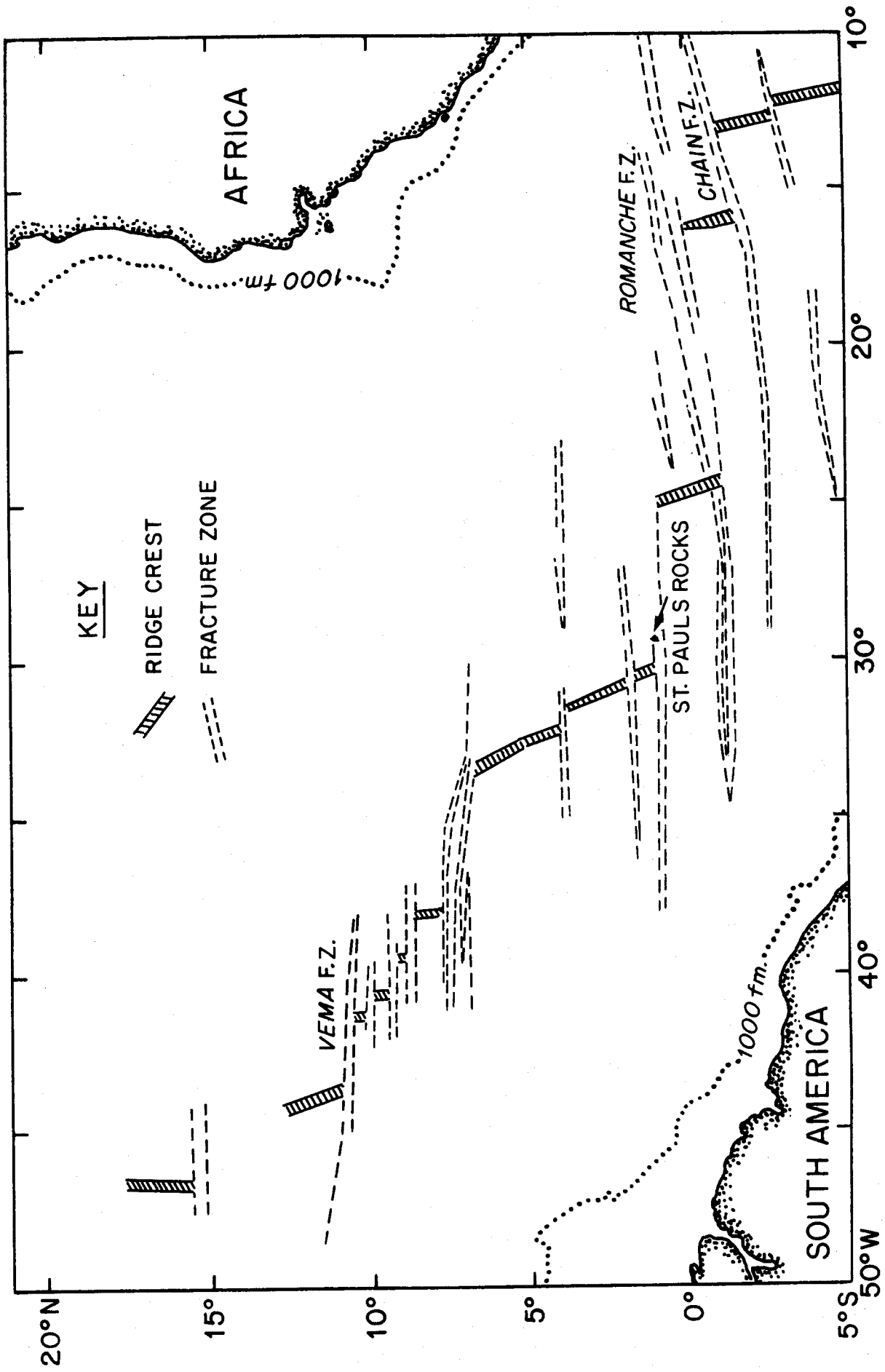


Figure 1

St. Paul's Rocks Location (from Heezen et al., 1964)

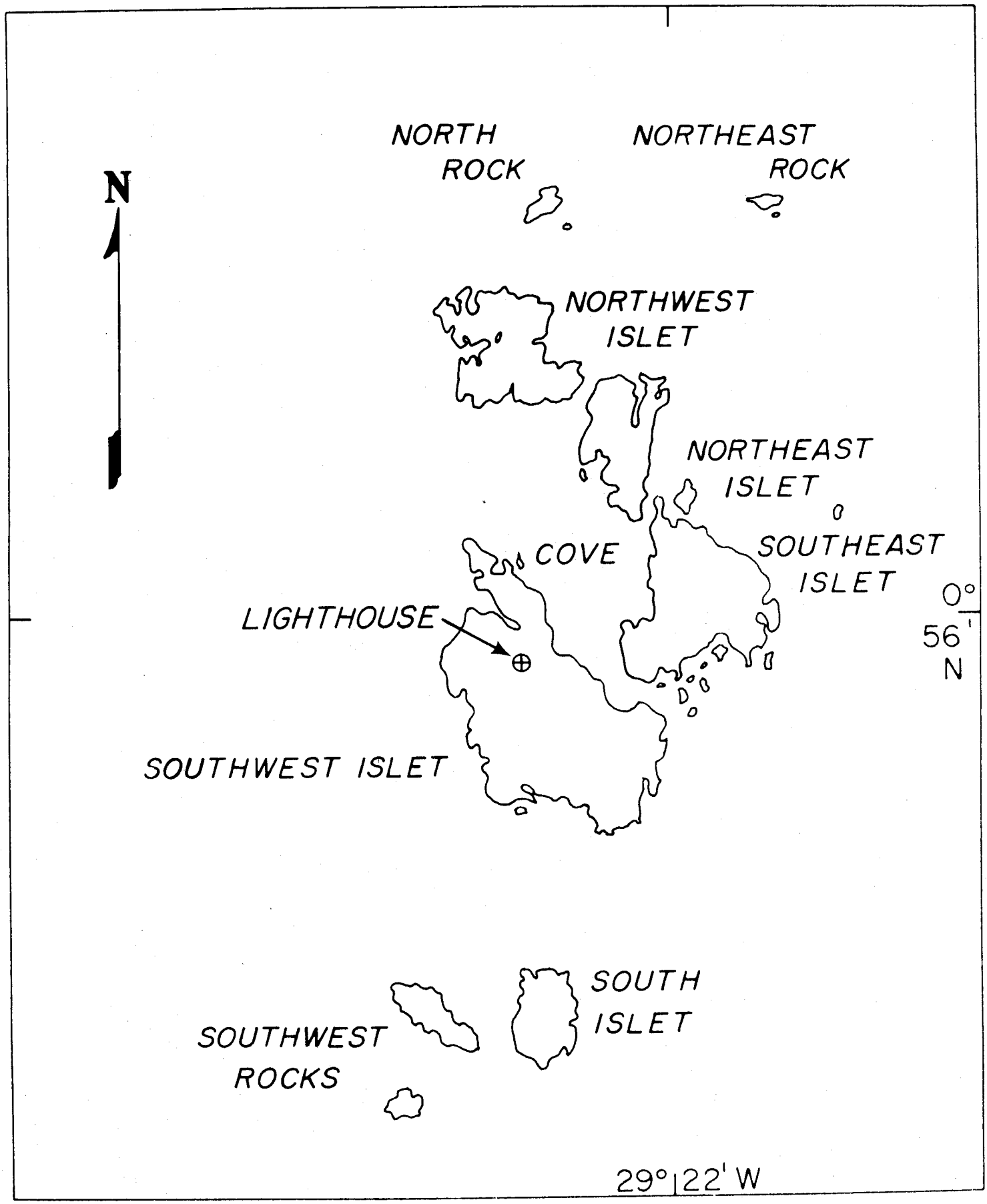


Figure 2

Individual Islets of St. Paul's Rocks

During Chain Cruise 35, 1963, the only landing was on the Southwest Islet where a number of specimens were obtained, including some orientated samples. Sampling of subsurface rocks by using explosive charges (0.46Kg blocks) was attempted, but with little success. In 1966, from Atlantis II, Cruise 20, landings were made on all islets and on South Rock. Drilling was attempted on Southwest Islet using a portable 2.5cm diameter, gasoline driven drill. The highly fractured nature of the rocks, however, caused breakage and jamming of the core in the barrel which required frequent stoppages to clear, hence only two holes were drilled. (The fresher peridotites of Northwest Islet would probably make a better drilling prospect).

Details of sample locations and rock types are given in Figures 3 to 6 and Table 1.

b. Surrounding Sea Floor:

Both coring and dredging were attempted on the sea-floor in the St. Paul's Rocks region during the two cruises. Coring was by a conventional piston core, a "free-fall" core (Sachs and Raymond, 1965), or a "dart" core (a high mass, high velocity gravity core). Dredging was by a conventional chain bag rock dredge with a small 10cm diameter pipe attached to retain sediment. Shallow water dredging in the near vicinity of the Rocks was by a 0.3m diameter pipe.

Details of sampling station locations and results are given in Figures 7 and 8 and Tables 2, 3 and 4.

(3) Bathymetry and Morphology:

a. St. Paul's Islets:

The sub-aerial expression of St. Paul's Rocks consists of five small

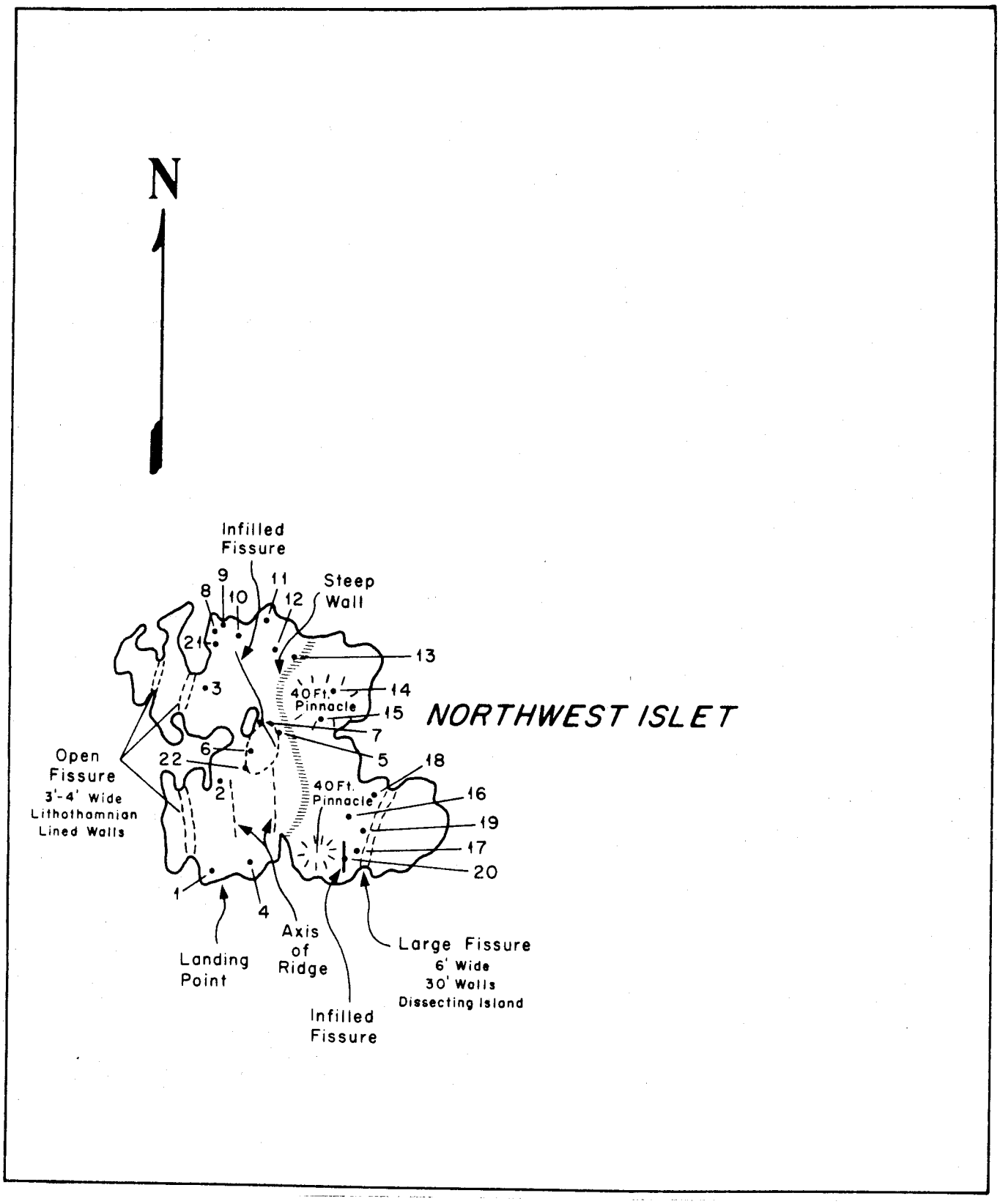


Figure 3

Northwest Islet, Sample Locations

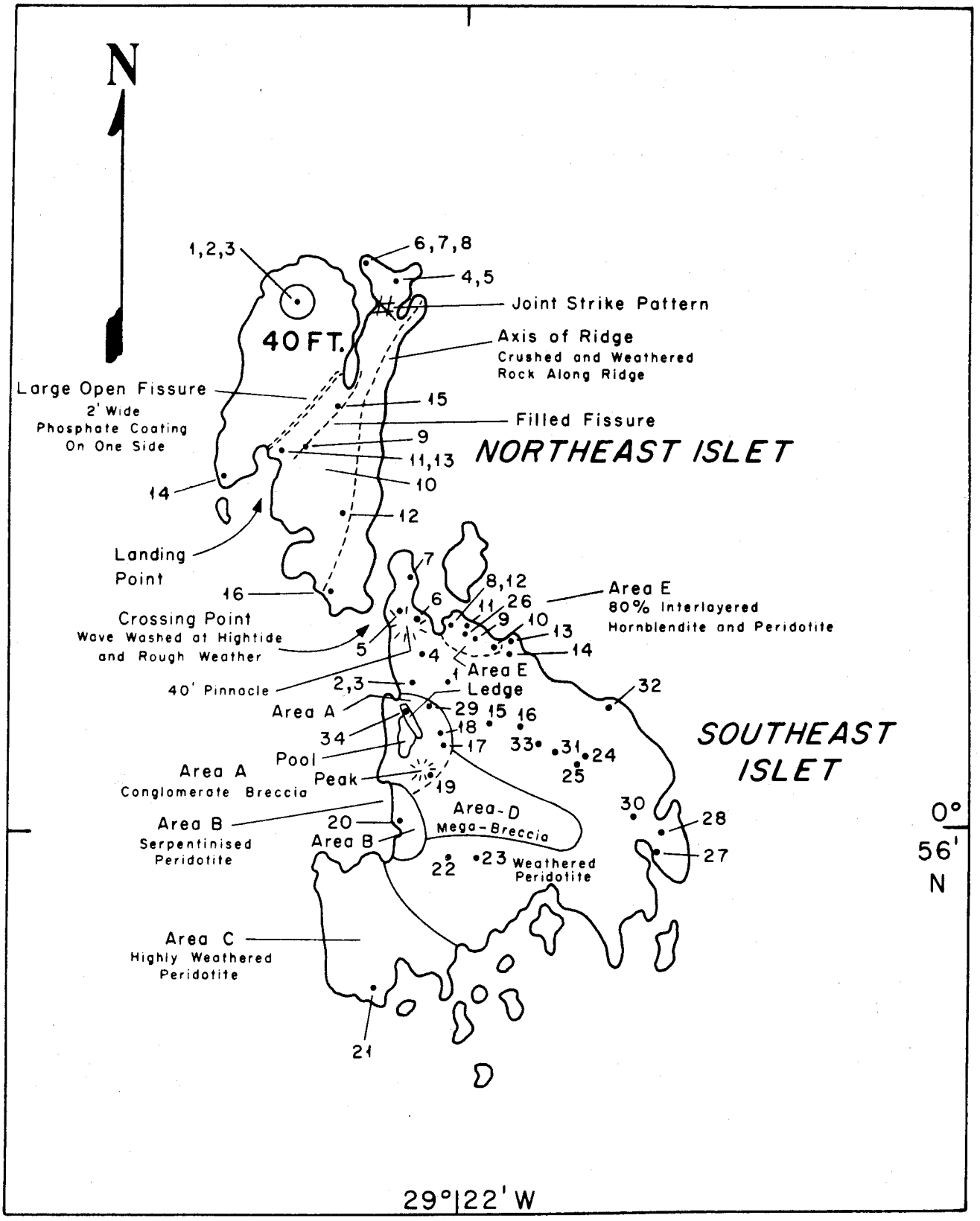


Figure 4

Northeast and Southeast Islets, Sample Locations

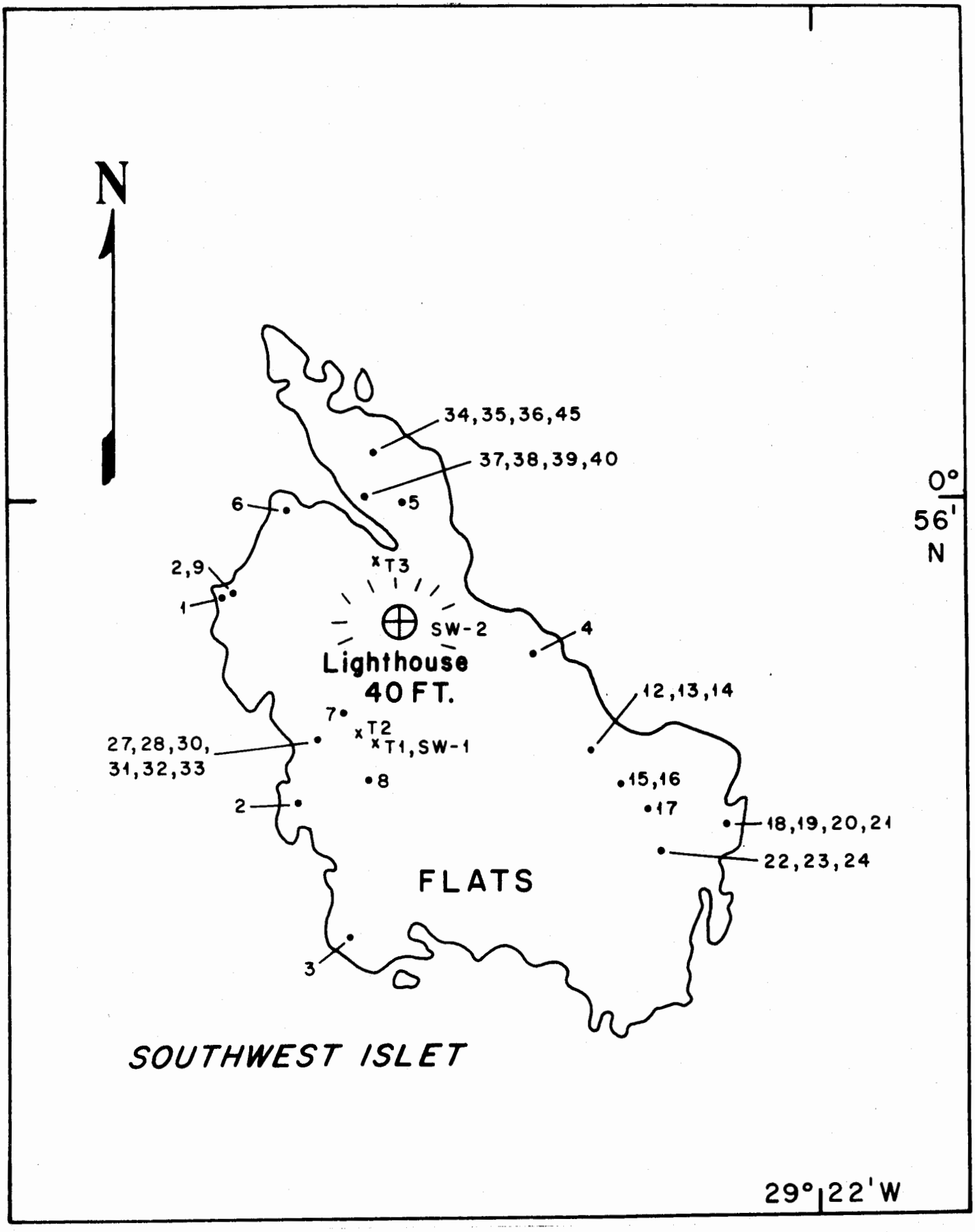


Figure 5

Southwest Islet, Sample Locations

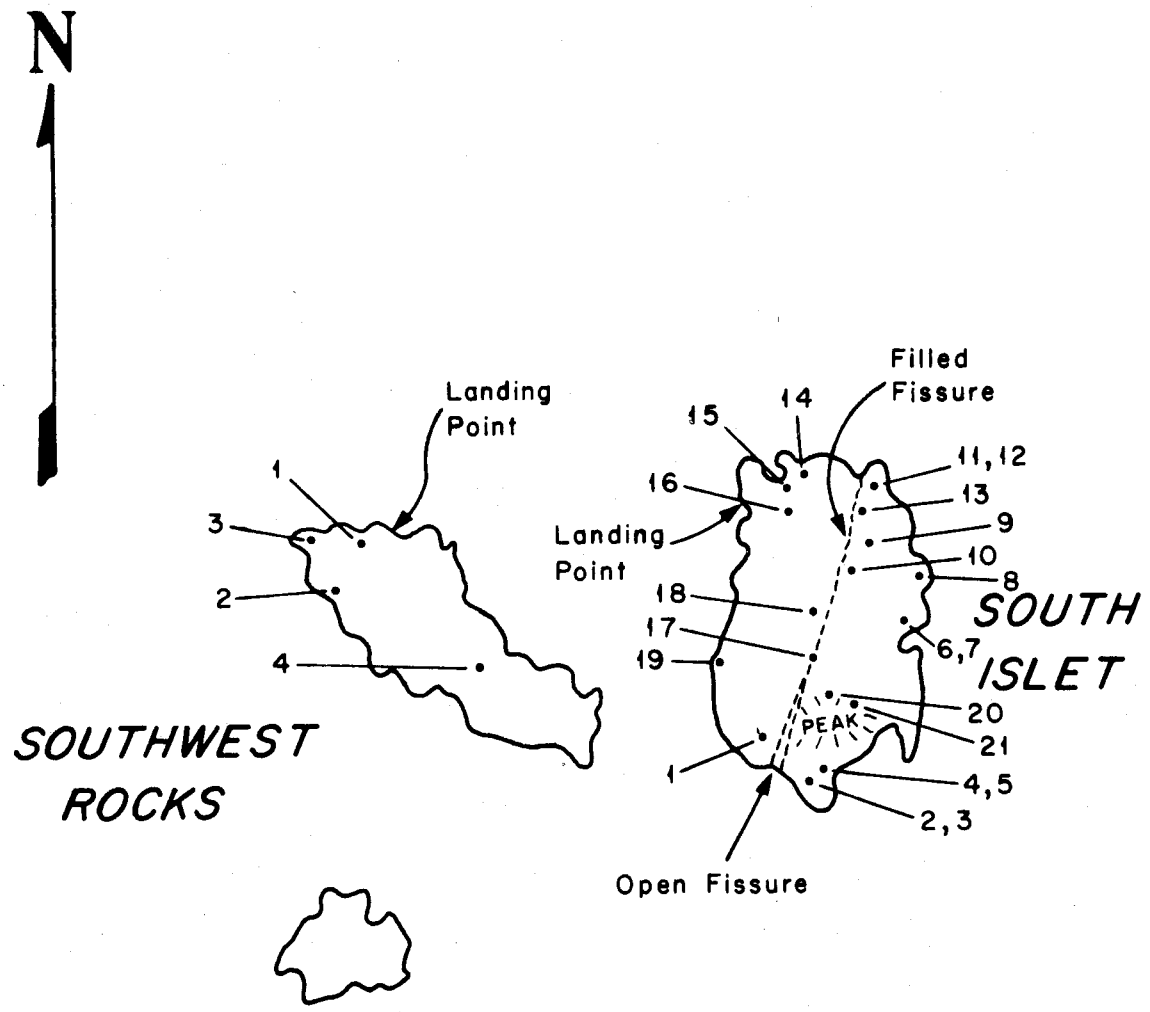


Figure 6

Southwest Rock and South Islet, Sample Locations

islets and four smaller rocks above the tidal and swell range; a few smaller pinnacles are occasionally visible above the waves. The extreme length or breadth of St. Paul's Rocks is less than 250 meters, their combined circumference about 0.8 Km. Figure 2 shows the outline and names of the principal islets and rocks taken from Tressler et al., (1956). All the islets are marked by rugged and irregular topography. The highest points, approximately 12m above sea level, are on Northeast and Southwest Islets; all the high peaks are guano-covered, particularly the lighthouse-bearing Southwest Islet which is the only one supporting nesting boobies and terns. The only significant relatively large level area is on the south side of Southwest Islet, a sprayed, pool-covered, flat region two to three meters above sea level.

Some topographic features of the islets are noted in Figures 3-6. The main fracture and fissure system trends in a N-S direction. All the features described by Tressler et al. still exist, however, it should be noted that Northwest Islet is cut by a large fissure at the eastern end. This is not noted on the maps of Tressler et al., but obviously existed as seen from Plate 8 of their report.

b. St. Paul's Massif:

In Figure 7, are shown the cruise tracks for the Chain and Atlantis cruises. Navigation was maintained by visual compass-fixing on the lighthouse, Southwest Islet, celestial navigation and dead reckoning during Chain 35 cruise, and radar fixing on the lighthouse plus celestial and dead reckoning navigation during Atlantis II, Cruise 20. Continuous echo sounding profiles were made using a Gifft 12 KHz transceiver, Edo transducer and the Alden Electronic Company Precision Graphic Recorder.

The precision time base sweep was calibrated for a velocity of sound in water of 4800 ft/sec. The echo sounding depth readings were plotted on the track lines at one-minute intervals with in-between soundings on peaks and troughs. These soundings are the basis for the contoured bathymetric map shown in Figure 8.

The St. Paul's massif is an elongate, ridge-like structure with an ENE strike of approximately 70°T. The St. Paul's Rocks are a very small expression of the form and bathymetry that compose this unique geological feature. The bottom is very irregular and rocky, though small local sediment ponds do exist on the sides. The bottom is very steep to the north and south of the axis with slopes of 1:2 to 1:5. The high point of the massif, the Islets, are not central but east of the center. Using the 3000m contour line as an arbitrary boundary to the feature, it is approximately 70 Km long by 22 Km wide. The St. Paul's Rocks lie approximately 20 Km from the eastern end and 50 Km from the western end. The feature thus has an ovate wedge shape.

The northern slope of the massif in the vicinity of the Rocks drops steeply down to a flat sediment-filled region at 3500m depth. To the south of the Rocks, the relief is much less regular, a pronounced step is seen at 1000m depth; a series of sediment covered steps also exist from 2800m down to a flat sediment-filled region at 3500m depth. To the east of the Rocks, the axis of the feature continues approximately 70° and the relief descends fairly steeply (slopes of 1:4-1:5) and regularly to 3000-3500m depth. To the west of the Rocks, the axis of the feature continues for approximately 8.0 Km then trends in an east-west direction with a much narrower ridge shape than in the vicinity of the Rocks. Profiles N-S, and E-W through the

St. Paul's Rocks (indicated as AA' and BB' in Figure 8),are shown in Figure 9.

c. Regional Bathymetry and Morphology:

In Figure 10b, the track lines for the Chain 35 and Atlantis II cruises are shown, also those of the Atlantis II Cruise 42, 1968. Soundings at five-minute intervals on these tracks have been used as the basis for the bathymetric contouring also shown in the same figure and in Figure 10a. This contouring has also been supplemented by a host of soundings from other vessels not yet published. We are grateful to Professor H. Hess, Princeton University, for allowing us access to, and use of these data.

Figure 1, showing the location of St. Paul's Rocks, indicates that they were closely related to the mid-Atlantic Ridge axis and a series of east-west fracture zones. Figure 10a,b, clarifies this relationship. The St. Paul's Rocks massif is an independent feature not apparently structurally related to the Ridge. To the northeast of the massif, high relief is apparent, although the elongate ridge and valley structures typically found in the Ridge axis are not present. These features, and the St. Paul's massif are bounded by a small escarpment immediately to the south, and which trends east-west although not apparently much beyond 27°W.

At about 25°W, and extending from 1°N to 1°S, high relief with a definite north-south axial trend may well represent a segment of the mid-Atlantic Ridge. Immediately to the south of this feature and trending east-west is a large escarpment extending beyond the range 22°W to 33°W seen in this figure. This feature is apparently part of the system of fracture zones found in the Equatorial Atlantic (Heezen et al., 1965) and probably related to the Romanche fracture zone. The scarp has a relief of approximately 1500m and slopes of

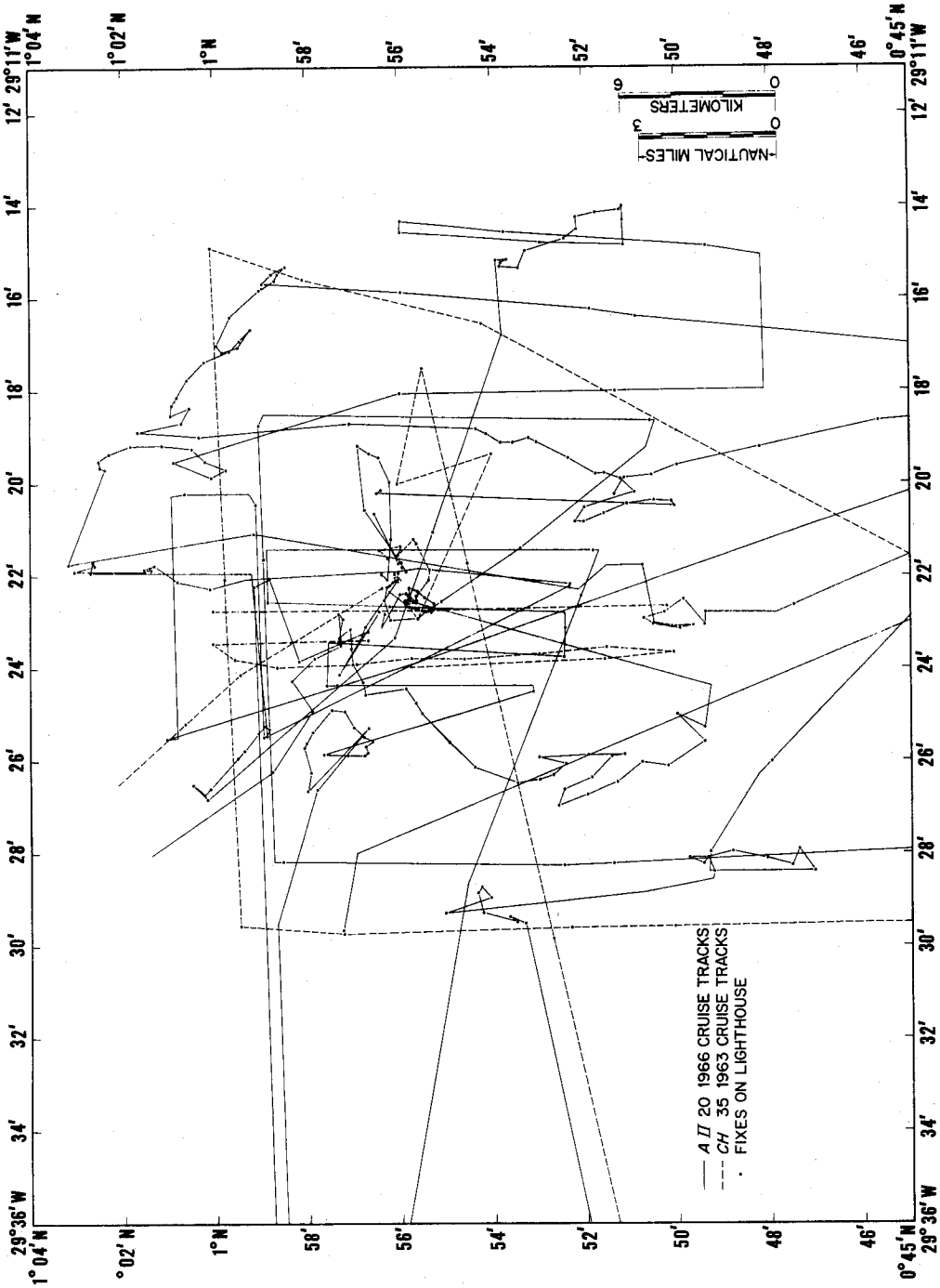


Figure 7

Cruise Tracks, St. Paul's Massif Locality

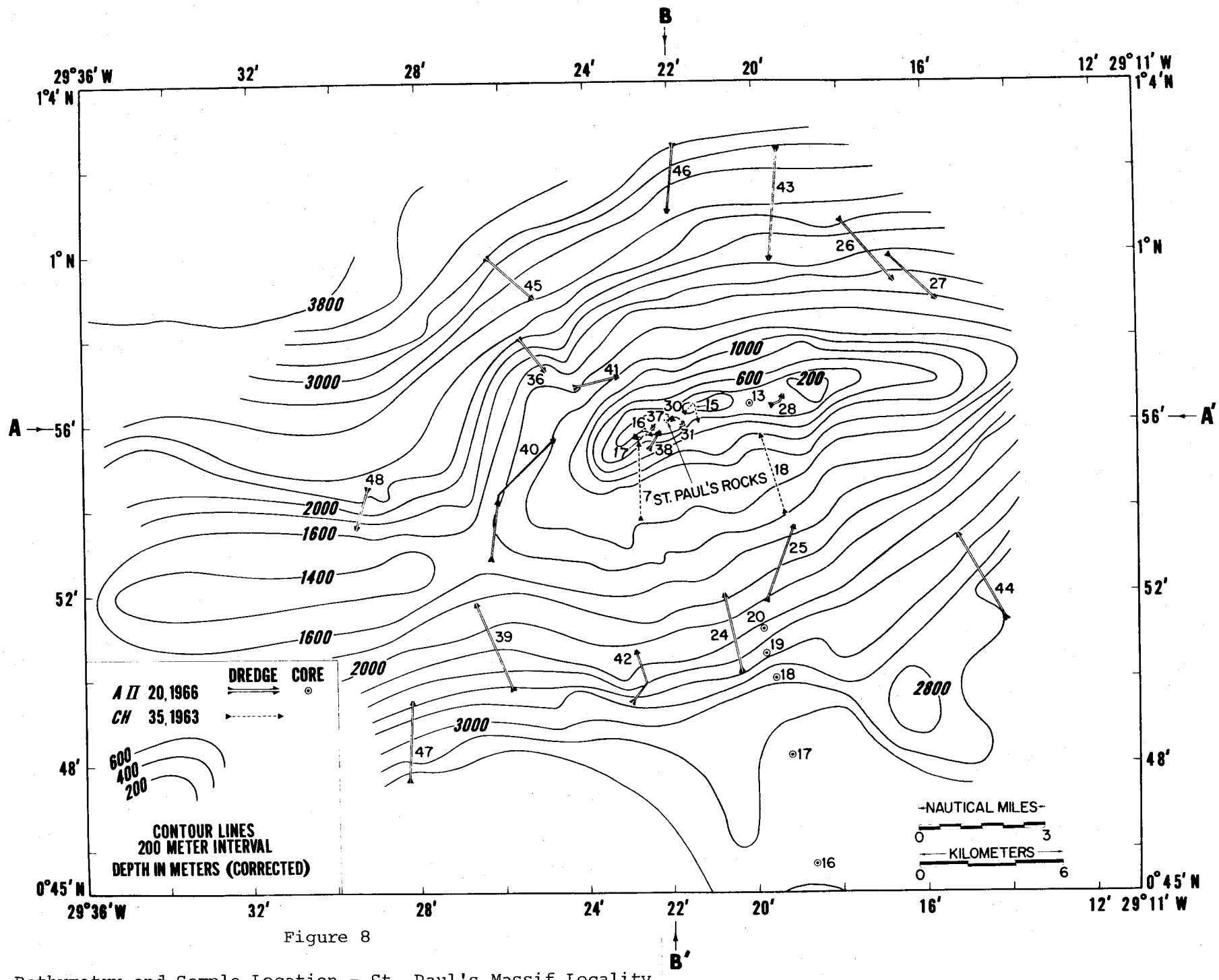


Figure 8

Bathymetry and Sample Location - St. Paul's Massif Locality

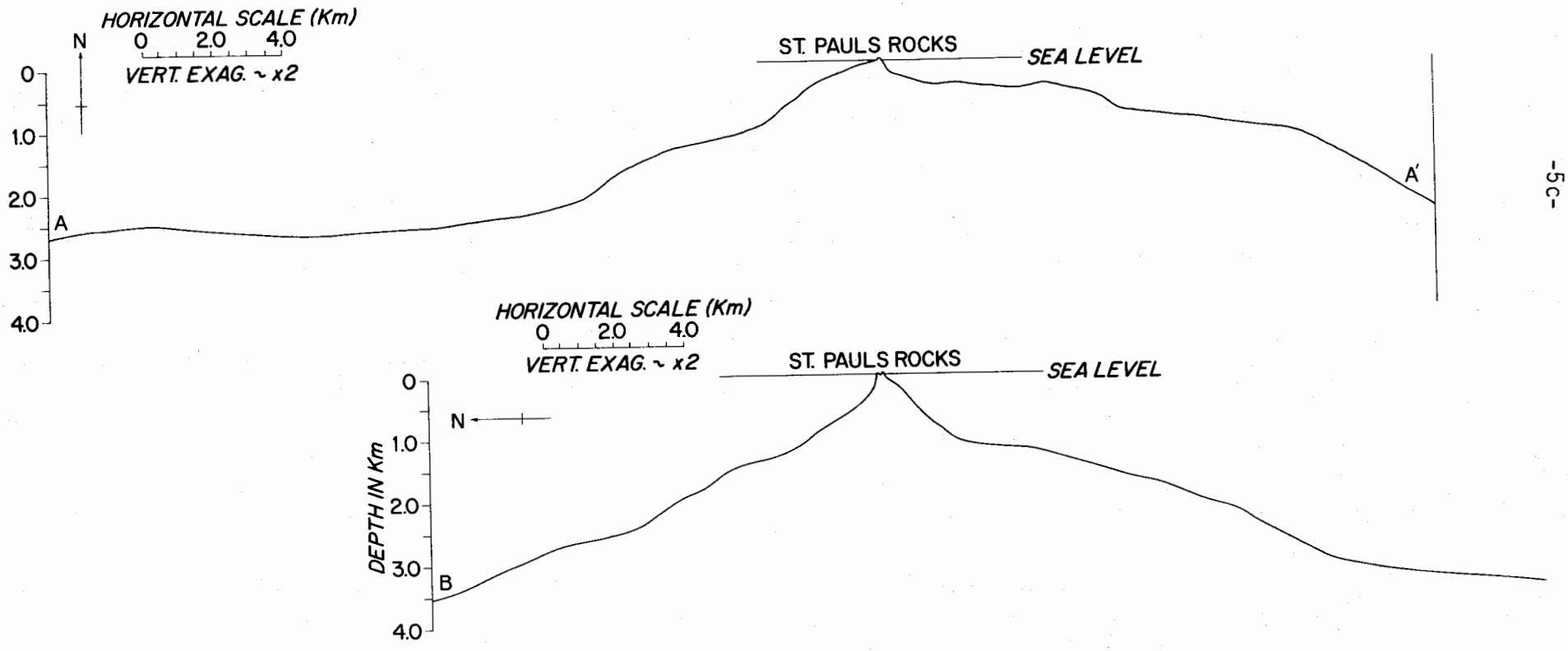


Figure 9

Profiles Through St. Paul's Massif

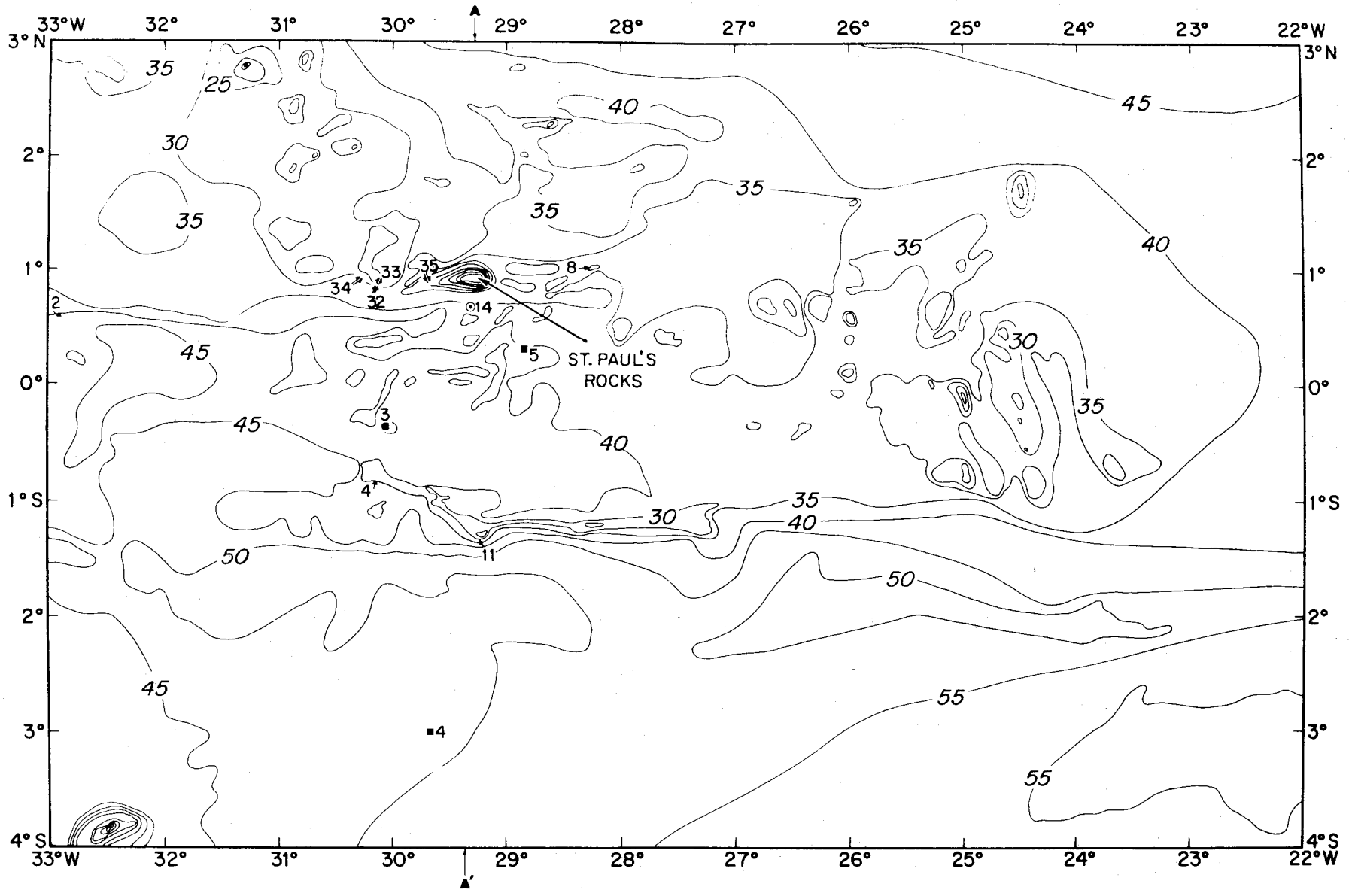
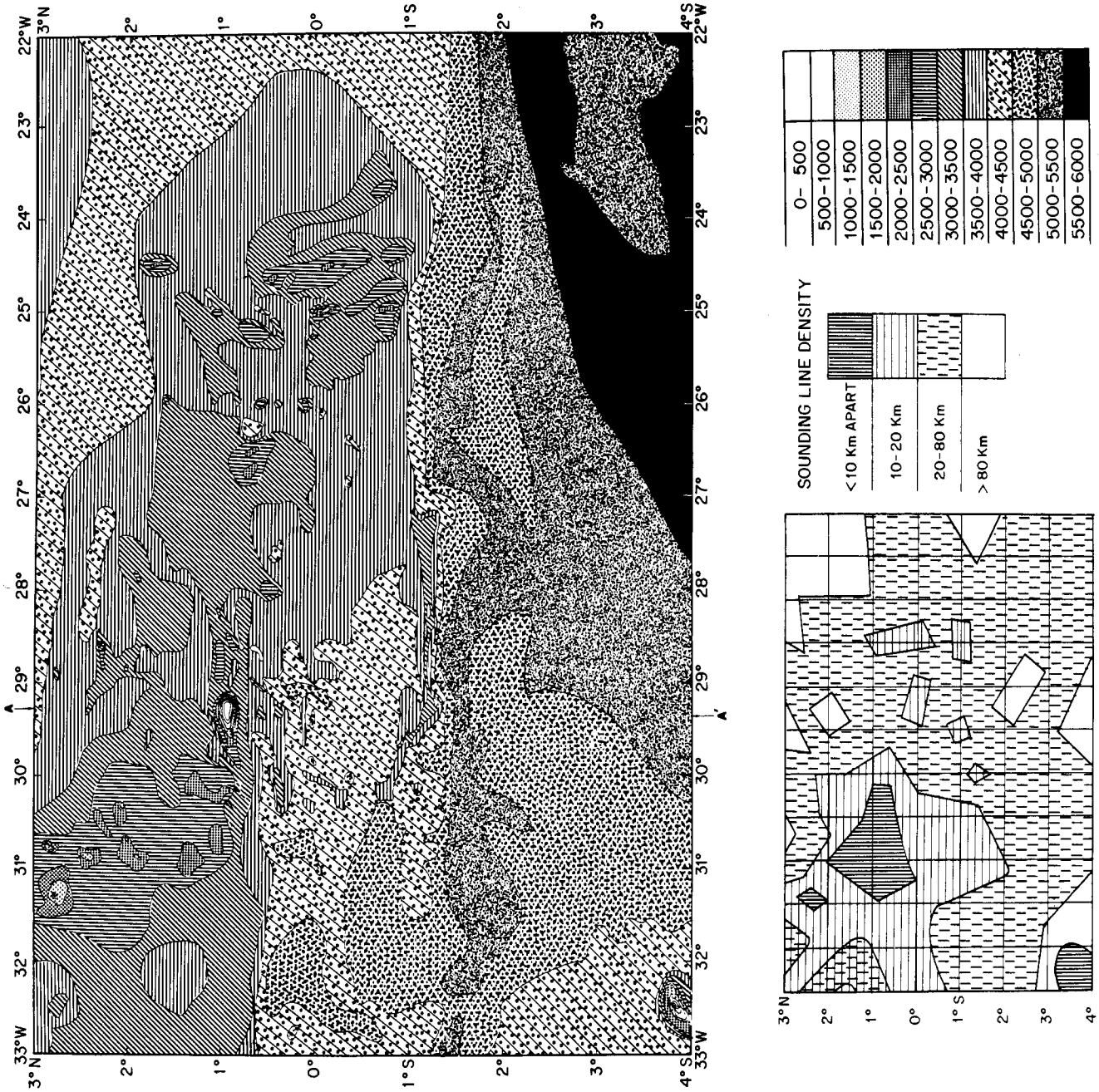


Figure 10a

Regional Bathymetry and Sample Locations, St. Paul's Fracture Zone

Figure 10b - Regional Bathymetry and Cruise Tracks, St. Paul's Fracture Zone.



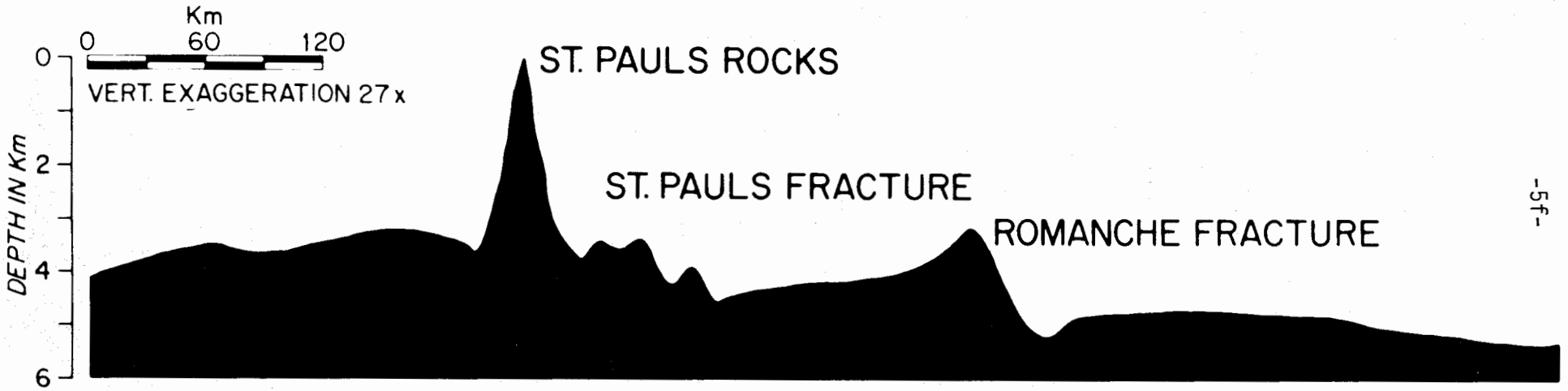


Figure 11

Profile Through St. Paul's Fracture Zone

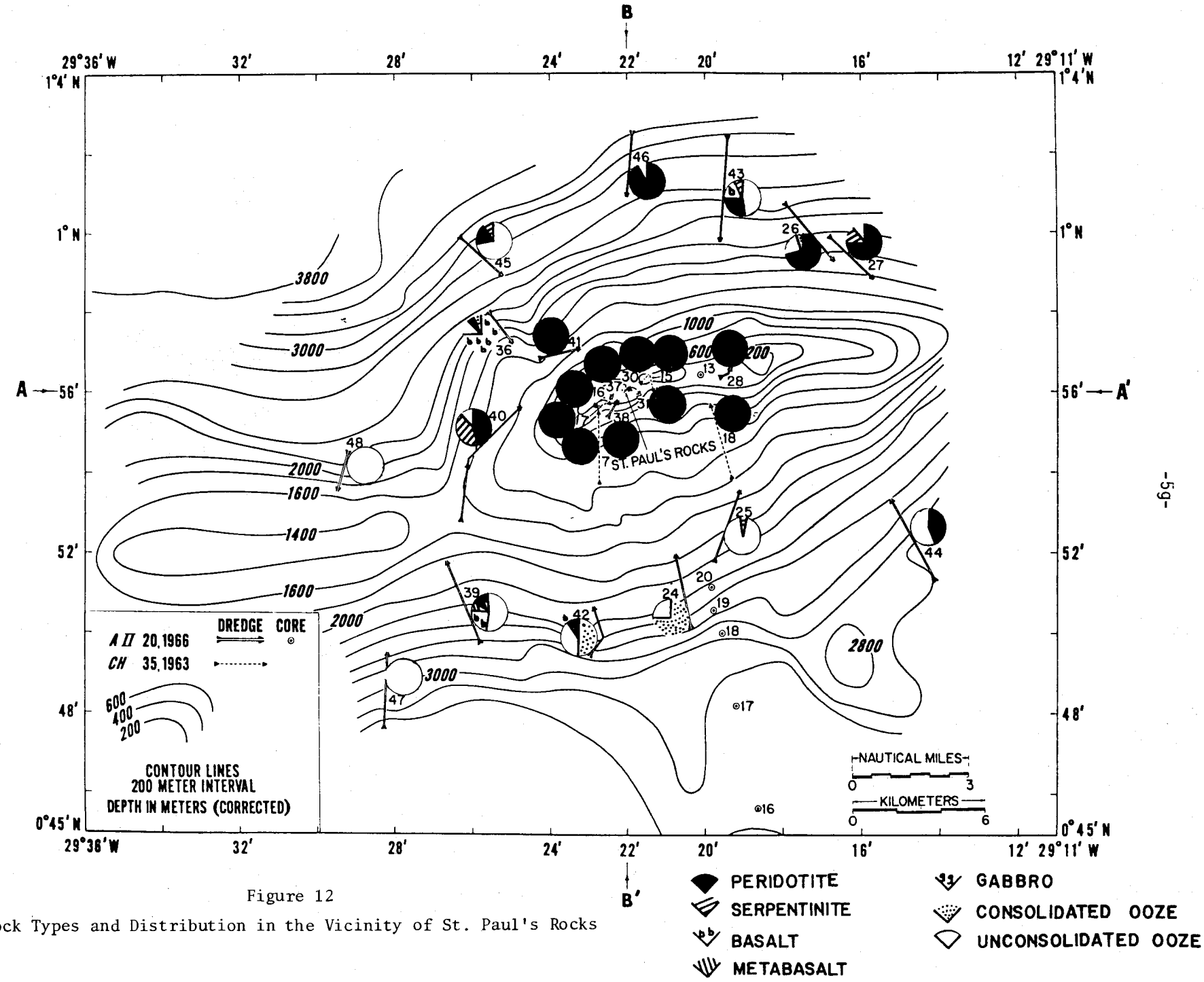


Figure 12

Rock Types and Distribution in the Vicinity of St. Paul's Rocks

1:5 to 1:12 are common.

(4) Geology:

a. St. Paul's Islets:

[1] Northwest Islet

(a) Peridotites

The islet composed predominantly of mylonitized peridotites which are less than 10% serpentinized. These peridotites are mainly aphanitic, they range from light gray to greenish gray on fresh surfaces, and commonly have a greasy lustre. They are consistently fresher on the north side of the islet and more weathered on the south side (Figure 3). Rarely, large porphyroclasts of pyroxene and dark brown spinel are visible, ranging to 1 cm in diameter. No compositional layering was found.

(b) Structure

The Northwest islet is characterized by extensive jointing in parallel sets mainly between 3 and 10 cm apart. Intersection of these joints produces the blocky, fragmental appearance which characterizes the islet. The joints show numerous orientations, although a N-S strike, east dipping set is particularly well developed. It is along this set that the major fissures have opened (Figure 3), and the N-S breccia fillings are also largely a reflection of this joint set. The serpentine-coated joints show very variable orientation with no major set observable.

The eastern edge of the islet is completely cut off from the main part of the islet by a deep impassable fissure, 2m wide and with 7m high walls, through which the sea surges.

(c) Near-Surface Phenomena

Where not coated by serpentine, the peridotites commonly weather to a rusty orange-brown. The spinel best survives the weathering and is commonly visible in even highly weathered peridotites. Where coated by serpentine, the peridotites are dark green. The outer edge of the islet at the tidal level, and in fissures through which the sea continually surges, are coated by lithothamnion.

Carbonate-phosphate breccias and conglomerates are well-displayed at several localities on the islet. The thickest and most continuous are orientated approximately north-south, are up to 1m wide, and pinch and swell along the strike; some may be traced 9-12m. Commonly, they occur as near-vertical fissure fillings, although some horizontal coatings are found. The matrix is a nearly white carbonate-phosphate, generally thinly layered. The lithic fragments are predominantly rusty, weathered peridotites. Shell debris is less common, but nearly always present. The lithic fragments range from angular to well-rounded and are consistent with entirely local derivation.

Guano is restricted to the upper peak and is not very extensive. Tide pools are less abundant than Southwest and Southeast Islets. Noddies are seen in abundance perching on cliff face, although not apparently nesting; boobies are very uncommon. Crabs are less abundant than on Southwest and Southeast Islets.

[2] Northeast Islet

(a) Peridotites

Rusty, weathered peridotites, similar to the southern part of Northwest Islet, predominate. Fresher, aphanitic peridotites were found at the northern edge of the islet. Interlayered peridotite-hornblendites

were not found.

(b) Structure

The jointing pattern is similar to Northwest Islet with a N-S to NE-SW set predominating. The major fissures run approximately NE-SW (Figure 4). The high point of the islet is at the northeastern end. The western end of the islet has a ridge running north-south; along the ridge, the rocks are distinctly more crushed and brecciated.

(c) Near-Surface Phenomena

Typical cemented breccia and conglomerate fissure fillings are common. Tidal pools are more common than Northwest Islet and are often filled with loose, rounded pebbles. The crush-breccia along the western ridge is more highly weathered to a yellowish-brown friable rock.

[3] Southeast Islet

(a) Peridotites

Southeast Islet is the most complex and most interesting geologically. The peridotites are similar to Northwest Islet with the fresher peridotites in the northern part of the islet. The peridotites from the southern part of the islet - area C in Figure 4 - are very highly weathered and altered. Area B (Figure 4) is characterized by peridotites more serpentinized than any from the other islets. Areas A and D (Figure 4) are predominantly composed of breccias; Area A, a conglomerate - breccia, Area D, composed of large displaced boulders - a megabreccia. The most significant rocks of the islet are the interlayered hornblendite-peridotites. They occur at a number of localities (Figure 4), but predominantly in Area E.

(b) Structure

The jointing and fissure pattern of Northwest Islet is also seen on Southeast Islet and north-south trends predominate. The main characteristic structures of the islet are shown in Figure 4. The large megabreccia in Area D, is composed of loose-lying, but large, boulders; it is not possible to see if they overlie normal peridotite. The interlayered hornblendite-peridotites strike between 130°-180° and dip 35-90°E.

(c) Near-Surface Phenomena

The cemented carbonate-phosphate breccias and conglomerates are similar to those found on the other islets except that the lithic fragments contain a significant proportion of hornblendite fragments. The hornblendite-rich rocks are less resistant to weathering and the banding is thus commonly etched in relief.

[4] Southwest Islet

(a) Peridotites

The islet is predominantly composed of weathered peridotites similar to the southern part of Northwest Islet. The flat-lying region at the southern end of the islet is characterized by highly weathered and fractured peridotites similar to Area C (Figure 5) on Southeast Islet.

(b) Structure

Southwest Islet is the largest of the islets and has the highest peak above sea-level. Fissure and jointing patterns are complex but predominate north-south. Tressler et al. (1956), show some of the main fracture patterns. Orientated samples were taken from this islet.

(c) Near-Surface Phenomena

This islet is characterized by the remains of the old

lighthouse erected by the Brazilians in 1930-31. The high peak is extensively covered with a hard, white, guano-derived phosphate covering. Boobies and terns are most abundant and are nesting. Massive and banded carbonate-phosphate fissure fillings and cemented conglomerates and breccias are common. The flat region of highly weathered peridotite (Figure 5) is marked by phosphate-carbonate fissure fillings giving a distinct boxwork structure. Lithothamnion-covered tidal surfaces circumscribe the islet.

[5] South Islet

(a) Peridotites

Rusty, weathered peridotites predominate; the northern end of the islet tends to be fresher. They are similar to those found on the southern part of Northwest Islet. One small area of interlayered hornblendite-peridotite is found at the northern edge (Figure 6).

(b) Structure

Parallel jointing sets, on a relatively small scale, give the islet somewhat of a blocky appearance. The predominant feature is a large fissure running approximately north-south and partially infilled with cemented breccia.

(c) Near-Surface Phenomena

Phosphate-carbonate cemented breccias and conglomerates are found as fissure infillings. Guano-covered outcrops are absent.

[6] Southwest Rocks

(a) Peridotites

Only the northernmost of the two subaerial exposures known as Southwest Rocks was visited. The peridotites were similar to those of

South Islet. The northwestern end of the islet was composed of interlayered hornblendite peridotites. A smaller outcrop of these rocks was also noted in the center of the Rock.

(b) Structure

The blocky appearance was due to intersecting joint sets as on South Islet. No major fissure or joints were noted.

(c) Near-Surface Phenomena

Similar cemented fissure fillings were seen as on South Rock, though less extensive.

b. Surrounding Sea Floor

1. Rock Types:

Rock types found in the immediate vicinity of St. Paul's Rocks are indicated on Figure 12 and Tables 1,2 & 3. They include mylonitized peridotites, some with interlayered hornblendite; serpentinized peridotites; basalt including weathered basalt and fresh vesicular alkali basalt; metamorphosed basalts; gabbro; consolidated oozes, limestones and dolostones, and unconsolidated ooze.

2. Distribution:

Some indication of the relative distribution of the various rock types is seen in Figure 12. The upper part of the massif is covered with mylonitized peridotite talus and other talus similar to that observed on the islets. Very little sediment cover is found or ferromanganese deposits. Organisms are abundant encrusting the talus in the very shallow upper levels and include algae, corals and sponges. Below 1000m, other rock types become more abundant. They include more serpentinized varieties of the peridotites, consolidated oozes, limestones and dolostones, basalt, including metamorphosed varieties, and in Dredge 39, some gabbroic rocks. The lower parts of the massif are predominantly covered with foraminiferal ooze, particularly below 3000m. Fresh vesicular alkali olivine basalt is found in Dredge 43 on the northern slope.

3. Relative Ages:

Sediments on the upper slopes above 1000m are Quaternary in age (Cifelli, 1970). The lower slopes are predominantly Miocene in age. Amongst the consolidated oozes and limestones, the ages are mostly late Miocene, but include mid-Miocene, Pliocene and one of Pleistocene age in Dredge 36 (Cifelli, 1970;

Thompson et al., 1968). The alkali basalt in Dredge 43 is associated with Quaternary sediments thought to have been caught up on the flow during eruption (Melson et al., 1967).

4. Geological Reconstruction:

The rock distribution and relative ages suggest diapiric intrusion of a mantle-derived peridotite (Melson et al., 1967, 1972) through older oceanic crust some time between mid-Miocene and the Quaternary. Talus from the islets now hides much of that history, but the edges around the talus show parts of that older oceanic crust - mostly weathered basalt - although the presence of gabbro suggests some deeper levels of the crust exposed.

The abundance and more pervasive serpentinization of peridotite around the margins suggests fluids accompanying the intrusion leading to the increased buoyancy and 'lubrication'. The metamorphosed varieties of basalt, some with slickenside features (Melson and Thompson, 1973) and the presence of a variety of lithified carbonates with diverse isotopic compositions (Thompson, 1973) co-existing in close proximity suggest alteration of the older oceanic crust in the immediate vicinity of the intrusion and associated with the actual intrusive event.

The lack of ferromanganese encrustations on the talus, suggests a relatively young feature, unless continued tectonic activity has supplied detritus from the islets until very recently. The Quaternary volcanism seen in the alkali basalts on the northern slope apparently broke through the talus and the basalts include many inclusions or xenoliths of mylonitized peridotite indicating that it postdates the diapiric intrusion of the peridotite.

Acknowledgements

Special assistance was given by the crews, officers, and scientific staff of the R/V Chain and the R/V Atlantis II during the 1963 and 1966 surveys of St. Paul's Rocks, particularly during the hazardous landing operations and close-in work around the islets. Dr. V. T. Bowen served as Chief Scientist during both these cruises; much credit goes to him for initiating and supporting the studies of St. Paul's Rocks. Dr.G. D. Nicholls supervised the geological studies during Chain 35 cruise and Dr. W. G. Melson during Atlantis II 20 cruise; the latter has been responsible for the major petrologic studies of the samples. Grateful acknowledgements are made to the late Harry Hess, who gave us access to some bathymetric data and to the late Professor Tilley, who encouraged our work and offered advice. All the colleagues who assisted in the sampling programs are indicated in the appropriate Tables. Their enthusiastic help was critical to the success of the cruises. Ms. Margaret Sulanowska assisted in the drafting of the figures.

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Table 1a SOUTHWEST ISLET: Cruise: Chain 35, Landing: March 18, 1963

Collectors: G. D. Nicholls, G. Thompson, P. L. Sachs, I. Macgregor

Sample Number	Description
1	Fine-grained, massive, blocky weathering, orientated sample ←320° at 74°W - peridotite.
2	As 1, orientated sample ←300° at 68°E - peridotite.
3	Fine-grained, massive, highly fractured, orientated sample ←006° at 71°W - peridotite.
	(↗ 316° at 74°E seems to be main fracture surface here, but there are many others which give rock blocky appearance).
4	Fine-grained, highly but irregularly fractured to small angular pieces, orientated sample ←036° at 45°SE - peridotite.
5	Fine-grained, highly fractured, orientated sample ←340° at 71°W - peridotite.
6	Fine-grained, coarse, blocky fracture pattern, orientated sample ←028° at 38°W - peridotite.
7	As 6, orientated sample ←310° at 91°SW (?) - peridotite.
8	As 6, orientated sample ←214° at 60°SE - peridotite.
	(Samples 1-8: Orientated samples collected by I. Macgregor and G. Thompson. Duplicate samples retained by Macgregor).
12, 13, 14	Suite of samples to illustrate cemented gravel deposit.
15, 16	Suite of samples to illustrate pebble conglomerate.
17	Pebble conglomerate.
18, 19, 20, 21	Suite of samples to illustrate calcareous deposit in clefts of peridotite.
22, 23, 24	Suite of samples to illustrate the same feature as 18-21.
25, 26	Serpentinized or mylonitized peridotite.
27, 28, 30, 31, 32, 33	Suite of samples illustrating variation in peridotite over restricted area (1 square yard).

Table 1a (Continued)

Sample Number	Description
29	Massive peridotite.
34, 35, 36, 45	Suite of samples collected from fresh exposures after blasting illustrating sequence from surface guano down to serpentinized peridotite.
37, 38, 39, 40	Suite of samples to illustrate phosphorus metasomatic effects on peridotite (obtained by hammer work on rocks).

Table 1a SOUTHWEST ISLET: Cruise: Atlantis II-20, Landing: March 19, 1966

Collectors: G. Thompson, R. Heath and J. Corliss

Sample Number	Description
SW-1	Upper weathered material from drill site T-1.
SW-2	Fresh guano from lighthouse floor.
T-1	First drill site, abandoned after 10 minutes. Weathering zone too friable and blocked core barrel.
T-2	Drill Site 2, approximately 1 meter from, and slightly higher elevation than, Site 1, 14.8 meters SSW of lighthouse. ∿200 cm of fairly fresh peridotite with weathered bands varying from 0.5 to 5 cm thickness. Core often broke at weathered bands and jammed in the core barrel. Upper 12 cm weathered, friable peridotite. 190-200 cm some orientation lost. Abandoned because of frequent core barrel blockage and difficulty in clearing.
T-3	Drill Site 3, 13.0 meters N of lighthouse. Abandoned after 50 cm penetration into peridotite with small bands of weathered material. Similar difficulty in drilling as Site 2.

Table 1b NORTHWEST ISLET: Cruise: Atlantis II-20, Landing: March 22, 1966

Collectors: W. G. Melson and G. Thompson

Sample Number	Description
NW-1	Rusty, weathered peridotite, joints generally spaced less than 1" apart, carbonate-phosphate veining.
NW-1a	Carbonate-phosphate vein filling; matrix >60% fragments rusty, weathered peridotite.
NW-1b	Rusty, weathered peridotite.
NW-1c	As 1b but with large spinel porphyroclasts.
NW-2	Rusty, weathered peridotite, a fresher block in a highly weathered zone, serpentine veins and carbonate coating.
NW-3	Slightly weathered peridotite, greasy lustre. Still in predominantly rusty, weathered zone.
NW-4	Blocky, reasonably fresh, greasy lustre, massive peridotite.
NW-5	Eastern wall of low flat area. Fresher blocks from rusty, weathered areas.
NW-6	Western wall of low flat area. Peridotite with large orthopyroxene and spinel porphyroclasts, no measurable layering, light buff weathering.
NW-7	Contact of comparatively fresh peridotite of NW part of islet and more weathered peridotite of flat zone to South. Very fresh peridotite, dark green on fresh surfaces.
NW-8	Greasy, massive peridotite, reasonably fresh. Blocky fracturing typical of much of the islet well developed here. Vein of carbonate/phosphate cemented breccia.
NW-9	Rusty, weathered peridotite with large orthopyroxene porphyroclasts about 6 mm diameter. Similar carbonate/apatite veins as NW-8, similar strike (N) and dip.
NW-10	Massive fresh peridotite, less than 10% serpentine (as are most of the peridotites on this islet). Fracturing (jointing) similar to strike of sedimentary breccia filling of NW-8 and NW-9. Main joints dip 45°SE, strike 45°.
NW-11a	As NW-10.
NW-11b	As NW-11a, but 3' south.

Table 1b (Continued)

Sample Number	Description
NW-12	Fresh, green, greasy lustre, peridotite. In this area (strike 20°, dip 30°E) well-developed jointing.
NW-13	Fresh, greasy, green peridotite from ledge on steep side of NW pinnacle, (material exceptionally fresh here).
NW-14	Rusty, weathered, peridotite, greenish-gray, greasy lustre on fresh surfaces, spinel porphyroclasts.
NW-15	Light gray peridotite, spinel porphyroclasts.
NW-16	Peridotite, dark brown coating.
NW-17	Peridotite, carbonate-phosphate coating on one side.
NW-18	Peridotite as NW-17.
NW-19	Peridotite, rusty, weathered on unserpentinized surface.
NW-20	Wall of carbonate/phosphate vein material containing rounded pebbles. Wall is weathered out 2-3' above surrounding peridotite and strikes 0°, dips 65°E.
NW-21	Carbonate/phosphate wall, lighter matrix.
NW-22	Rusty, weathered peridotite, (typical of weathered surfaces of NW Islet), carbonate-phosphate-coated joints.

Table 1c SOUTHEAST ISLET: Cruise: Atlantis II-20, Landing: March 19, 1966

Collectors: W. G. Melson and T. Moore

Sample Number	Description
SE-1	Block with copper stained "malachite" surface-hornblendite.
SE-2	Joint filling of clastic rocks in matrix - phosphate/carbonate.
SE-3	Same location as SE-2 - fragment of conglomerate.
SE-4	Hornblende and serpentine layers in peridotite, layering strike 175°, dip 35°E - interlayered hornblendite peridotite.
SE-5a	Large porphyroclasts of pyroxene in peridotite.
SE-5b	Strike 175°, dip 50°E, location 2'NW of SE-5a - peridotite.
SE-6	Primary breccia - large block of hornblendite in peridotite.
SE-7	Block of hornblende-peridotite.
SE-8	As SE-7, hornblende weathered in relief.
SE-9	Hornblende-rich layers in peridotite. (Strike 170°, dip 55°E - orientation may be slightly changed by abounding joint).
SE-10	Interlayered hornblendite-peridotite. (Strike 135°, dip 90° - abundant jointing may influence strike and dip. 1st block east of peak, from which sample was taken (from the south end of the block) may have moved as unit - layering strike 180°, dip 60°E).
SE-11	Peridotite with hornblende layers.
SE-12	Serpentinized peridotite.
SE-13	Hornblendite (large crystals).
SE-14	Cemented sandstone vein filling - phosphate/carbonate sediment.
SE-15	Cemented sandy conglomerate - phosphate/carbonate sediment.
SE-16	Breccia of serpentinized peridotite with hornblende fragments.
SE-17	Fragmental carbonate sediment, with abundant tests.

Table 1c (Continued)

Sample Number	Description
SE-18	Pebble conglomerate (taken at basal contact of flat sheet of conglomerate with underlying hornblendite).
SE-19	Calcareous breccia, including large barnacle.
SE-20	Intensely jointed, largely serpentinized peridotite.
SE-21	Weathered peridotite.
SE-22	Layered hornblendite-peridotite.
SE-23	Weathered serpentinite w/relict peridotite zone, strike 145°.
SE-24	Massive hornblendite.
SE-25	Rusty, weathered peridotite, hornblende layers.
SE-26	Broken lithothamnion (not in situ).
SE-27	In situ lithothamnion.
SE-28	Peridotite with hornblende layers.
SE-29	Interlayered peridotite and hornblendite.
SE-30	Hornblendite.
SE-31	Hornblendite (from zone striking 160°, malachite stains).
SE-32	Light gray peridotite, partially serpentinized.
SE-33	Vertical fracture filling in hornblendite zone of sample SE-31, calcareous cemented conglomerate.
SE-34	Rusty, weathered peridotite.

Table 1d NORTHEAST ISLET: Cruise: Atlantis II-20, Landing: March 19, 1966

Sample Number	Description
NE-1	Weathered fine-grained rock broken by small joints - peridotite.
NE-2	Black fissure filling - phosphate/carbonate sediment.
NE-3	Very weathered yellow powdery rock - possibly weathered crush-breccia.
NE-4	Dense, massive, dull gray-olive-green, peridotite apparently little weathered and containing 0.5-1 mm spinel porphyroclasts. Rock is translucent green on thin slivers.
NE-5	Large piece similar to NE-4 - peridotite.
NE-6	As NE-4, possibly more and larger minerals - peridotite.
NE-7	Very dense, almost glassy grayish-olive, relatively unfractured. A few dark veins, no crushed rock apparent within 2 m - peridotite.
NE-8	Large piece as NE-7 - peridotite.
NE-9	Breccia-conglomerate from large vein - phosphate/carbonate sediment, box work structure.
NE-10	Collection of the most rounded of the cobbles and pebbles from potholes and spray pools of the south-central part of the islet.
NE-11	Dense, massive, more grayish rock than previous, small crystals present - peridotite.
NE-12	Cemented conglomerate - phosphate/carbonate sediment.
NE-13	Vein or fissure filling - phosphate/carbonate sediment.
NE-14	Dark gray, fractured fine-grained rock - peridotite.
NE-15	Crushed serpentinized rock - peridotite.
NE-16	Stalagmitic material lining small cavity. Reddish-brown outside, biscuit-colored inside with green layer just under surface - phosphate/carbonate sediment.

Table 1e SOUTH ISLET AND SOUTHWEST ROCKS: Cruise: Atlantis II-20, Landing: 3/22/66

Collectors: P. L. Sachs and T. Moore

Sample Number	Description
	(SOUTH ISLET)
S-1	Blocky, weathered rock with small black spinels (probably least weathered and jointed material on islet) -peridotite.
S-2	Light olive-brown, weathered rock - peridotite.
S-3	Coarse crystalline, yellowish brown vein filling (possibly different from other islets) - phosphate/carbonate sediment.
S-4	Weathered fissure filling with enclosed peridotite pebbles - phosphate/carbonate conglomerate.
S-5a	Light olive-brown blocky rock with large spinels and serpentine filling (?) - peridotite.
S-5b	Lithothamnion with algae and sponge.
S-5c	Sea urchin.
S-6	Gray, blocky rock - peridotite
S-7a	Calcareous algae and sea-urchin.
S-7b	Barnacles.
S-8	Weathered peridotite.
S-9	Fragments of large, rounded (by weathering?) block located in fissure (rounded by wave wash) - peridotite?
S-10	Gray fragment from block less jointed than surrounding area - peridotite.
S-11	Grayish rock with thin bands of hornblende, bands strike 080°, dip 60°S - interlayered hornblendite-peridotite?
S-12	As 11.
S-13	Dark gray, relatively unweathered rock - peridotite.
S-14	Dark gray rock - peridotite.
S-15	Weathered breccia infilling fissure - phosphate/carbonate sediment.

Table 1e (Continued)

Sample Numbers	Description
S-16	Dense, dark gray rock - peridotite.
S-17	Two types of fissure filling in same fissure. Fissure vertical, N-S strike. White material on both sides of fissure and continuous with joint filling in surrounding rocks. Soft brown east of center filling (brown filling subsequent to white?) - phosphate/carbonate sediment.
S-18	Dense gray peridotite.
S-19	Weathered brown fissure filling - phosphate/carbonate sediment.
S-20	Weathered gray peridotite.
S-21	Highly jointed, weathered, vein-filled rock common over most of the islet - peridotite.
S-22	Sea anemone.
	(SOUTHWEST ROCKS)
SWR-1	Dip 60°SW layered hornblendite-peridotite.
SWR-2	As SWR-1.
SWR-3	As SWR-1.
SWR-4	As SWR-1.

Table 2: R/V CHAIN, CRUISE 35: DREDGE LOCATIONS AND RESULTS, ST. PAUL'S ROCKS REGION

Number	Equipment	Date	On Bottom Off Bottom	Time*	Depth* (meters)	Bearing† / Latitude	Distance† / Longitude	Result
CH35-2	Rock Dredge With Chain Bag and 10cm Pipe	3-12-63	On Off	0954 1059	3937 3367	00°35'N 00°36'N	32°54.5'W 32°57'W	Small Cobble (2kg) of Mn-crusted basalt. Some small pieces of altered basalt and Mn-crust. Some small pieces of Mn-stained consolidated clay.
CH35-4	Rock Dredge With Chain Bag and 10cm Pipe	3-17-63	On Off	0418 0640	4320 3561	00°52.5'S 00°55.5'S	30°07.8'W 30°08.5'W	Large boulder (20kg) of Mn-crusted, altered basalt. Some small pieces of highly weathered basalt. Some small pieces of Mn-stained consolidated clay.
CH35-7	Rock Dredge With Chain Bag and 10cm Pipe	3-18-63	On Off	1140 1315	1126 198	017°T 053°T	3.86 km 1.29 km	Large haul of mylonitized peridotites (45kg) similar to islet types. Several rocks encrusted by algae and other organisms, some corals and pelycepods.
CH35-8	Rock Dredge With Chain Bag and 10cm Pipe	3-19-63	On Off	0330 0707	3219 2626	00°57'N 01°00'N	28°22'W 28°16'W	One piece of glass-rimmed basalt; two large and 24 small pieces of consolidated foram ooze. Some unconsolidated foram ooze.
CH35-11	Rock Dredge With Chain Bag and 10cm Pipe	3-23-63	On Off	0026 0640	4353 3747	01°24.5'S 01°20'S	29°12'W 29°17.5'W	Three large pieces of metabasalt; some small pieces of serpentinite. Several small pieces of consolidated foram ooze and sepiolite-rich sediments.

Table 2: (Continued)

Number	Equipment	Date	On Bottom / Off Bottom	Time*	Depth* (meters)	Bearing† / Latitude	Distance† / Longitude	Result
CH35-15	0.3m Pipe Dredge	4-13-63	On	1140	282	244°T	0.80 km	Several pieces of mylonitized peridotite and breccias similar to islet types.
			Off	1200	170	275°T	1.13 km	
CH35-16	0.3m Pipe Dredge	4-13-63	On	1255	161	051°T	0.97 km	Corals, several rocks encrusted by algae and other organisms.
			Off	1345	95	072°T	0.89 km	
CH35-17	0.3m Pipe	4-13-63	On	1400	121	074°T	0.80 km	Mainly corals; few rocks encrusted with algae and other organisms.
			Off	1423	143	064°T	1.45 km	
CH35-18	Rock Dredge With Chain Bag and	4-13-63	On	1445	1414	307°T	5.47 km	Approximately 70kg of mylonitized peridotites and breccias similar to islet types.
			Off	1650	969	277°T	7.24 km	

*Times given are those when the dredge first reached and finally left bottom. Depths are those under the ship at those times given in meters and corrected for the velocity of sound in water.

†Bearings and distances are ships ranges from Lighthouse, Southwest Islet, based on dead reckoning and/or visual compass sighting. Locations beyond that range are given as latitude and longitude and are based on dead reckoning and celestial navigation.

Table 3: R/V ATLANTIS II, CRUISE 20: DREDGE LOCATIONS AND RESULTS, ST. PAUL'S ROCKS REGION

Number	Equipment	Date	On Bottom / Off Bottom	Time*	Depth*	Bearing† / Latitude	Distance† / Longitude	Result
AII20-24	Rock Dredge With Chain Bag and 10cm Pipe	3-18-66	On Off	1038 1200	2542 1719	344°T 343°T	9.90 km 6.73 km	Approximately 9kg consolidated foraminiferal ooze (1 large block, 4kg, with stratigraphy preserved. Approximately 20kg dolostones (some boulders up to 6kg). White, plastic clay and foram sands.
AII20-25	Rock Dredge With Chain Bag and 10cm Pipe	3-18-66	On Off	1330 1510	2057 1463	331.5°T 306.5°T	7.80 km 5.92 km	Mainly calcareous mud with some ultramafic rock-derived mineral sands. Some serpentinite fragments. Small horn coral.
AII20-26	Rock Dredge With Chain Bag and 10cm Pipe	3-18-66	On Off	1700 2000	2377 1664	215°T 239°T	9.80 km 10.14 km	Approximately 20kg partly serpentinized mylonite peridotites and breccias. Calcareous mud and sands.
AII20-27	Rock Dredge With Chain Bag and 10cm Pipe	3-18-66	On Off	2100 2300	1948 1509	232°T 247°T	10.30 km 11.26 km	Approximately 80kg mylonitized peridotites and breccias similar to islets. Some sedimentary breccias with crystalline aragonite. Calcareous and mineral-rich sands.
AII20-28	0.3m Pipe	3-19-66	On Off	1020 1050	201 219	261.5°T 256°T	3.94 km 4.51 km	Several corals, some rocks encrusted with algae and other organisms.

Table 3: (Continued)

Number	Equipment	Date	On Bottom Off Bottom	Time*	Depth*	Bearing† / Latitude	Distance† / Longitude	Result
AII20-29	10cm Pipe	3-19-66	On	1200	<50m	081°T	0.13 km	Sponges, algae encrusted rocks.
AII20-30	0.3m Pipe	3-19-66	On Off	1325 1335	59 77	272°T 242°T	0.16 km 0.16 km	Sponges, algae, bivalves and other organisms encrusting rocks.
AII20-31	0.3m Pipe	3-19-66	On Off	1425 1445	183 183	267°T 286°T	0.51 km 0.40 km	Approximately 45kg mylonitized peridotites and breccias similar to islet-types. Many encrusted with sponges, algae mollusks and other organisms.
AII20-32	Rock Dredge With Chain Bag and 10cm Pipe	3-20-66	On Off	1500 1710	3292 2332	0°45.5'N 0°54.4'N	30°08.0'W 30°06.0'W	Calcareous mud and sands with abundant peridotite-derived minerals and fragments. One large deep-sea fish.
AII20-33	Rock Dredge With Chain Bag and 10cm Pipe	3-20-66	On Off	1830 2100	2707 2286	0°54.4'N 0°59.3'N	30°06.0'W 30°04.0'W	Calcareous mud and sand.
AII20-34	Rock Dredge With Chain Bag and 10cm Pipe	3-21-66	On Off	0315 0600	2579 2432	0°54.8'N 0°57.8'N	30°17.0'W 30°15.5'W	Approximately 130kg of basalts. Many weathered with Mn coating, but some with relatively fresh glass surfaces.
AII20-35	Rock Dredge With Chain Bag and 10cm Pipe	3-21-66	On Off	1150 1600	3530 2213	1°00.5'N 0°58.8'N	29°42.8'W 29°45.8'W	A few pieces of loosely consolidated foraminiferal ooze. Some clinker and Mn crust. Calcareous mud and sand, and one horn coral and a large nudibranch.

Table 3: (Continued)

Number	Equipment	Date	On Bottom / Off Bottom	Time*	Depth*	Bearing† / Latitude	Distance† / Longitude	Result
AII20-36	Rock Dredges With Chain Bag and 10cm Pipe	3-21-66	On Off	2130 0030	2304 1463	119°T 102.5°T	6.76 km 5.63 km	Approximately 13kg of partially weathered basalt, including some tuffs and breccias. A few pieces of serpentinized periodotite and some fragments of talc schist. A few small pieces of hard, deuse lithified limestone and a few pieces of chalky, friable consolidated foraminiferal ooze. Some calcareous mud and sand.
AII20-37	0.3m Pipe	3-22-66	On Off	1100 1126	128 82	087°T 062°T	0.51 km 0.80 km	Some corals, several rocks encrusted by algae, sponges and other organisms.
AII20-38	0.3m Pipe	3-22-66	On Off	1300 1348	475 137	035°T 059°T	1.48 km 0.64 km	Some rocks encrusted by algae, sponges, corals and other organisms. Some shell and rock sand.
AII20-39	Rock Dredge With Chain Bag and 10cm Pipe	3-22-66	On Off	1554 1930	2606 1829	030°T 056°T	11.83 km 9.66 km	Approximately 9kg of basalts and metabasalts (includes tuffs and slickensided basalt fragments); 1.5kg of serpentinized peridotite and hornblendites. 1kg of coarse gabbroic rocks; 2.5kg mudstones, tuffaceous limestones and sedimentary breccias; 25 kg of consolidated ooze and foraminiferal limestone.

Table 3: (Continued)

Number	Equipment	Date	On Bottom / Off Bottom	Time*	Depth*	Bearing† / Latitude	Distance† / Longitude	Result
AII20-40	Rock Dredge With Chain Bag and 10cm Pipe	3-22-66	On Off	2151 0006	1463 1143	052°T 082°T	8.69 km 4.34 km	Approximately 25kg of mylonitized peridotites similar to islet types. Some consolidated foraminiferal ooze and sedimentary breccias; some gravel and sand of rock fragments and foraminiferal ooze. Some organisms including coral and a gorgonian.
AII20-41	Rock Dredge With Chain Bag and 10cm Pipe	3-23-66	On Off	0100 0245	1390 1116	109°T 144°T	3.78 km 2.41 km	Approximately 60kg mylonitized peridotite similar to islet types; some sedimentary breccias; gravel and sand, very little foraminiferal ooze; two gorgonians.
AII20-42	Rock Dredge With Chain Bag and 10 cm Pipe	3-23-66	On Off	1215 1630	2743 2067	007.5°T 006.0°T	10.62 km 8.85 km	Fourteen pieces of rock including porphyritic basalt (1.2kg), chloritized basalt breccias and tuffs; 0.7kg mudstones; 15kg consolidated foraminiferal ooze; 12kg foraminiferal ooze and sand
AII20-43	Rock Dredge With Chain Bag and	3-23-66	On Off	1905 2155	2908 1993	201°T 212°T	11.26 km 7.08 km	Approximately 60kg rock including 24kg of vesicular fresh, alkali basalt with xenoliths and xenocrysts; 36kg mylonitized pridotites similar to islet types; some carbonate breccias; abundant dark gray mud and foraminiferal ooze.

Table 3: (Continued)

Number	Equipment	Date	On Bottom / Off Bottom	Time*	Depth*	Bearing† / Latitude	Distance† / Longitude	Result
AII20-44	Rock Dredge With Chain Bag and 10cm Pipe	3-24-66	On Off	0230 0545	3017 2304	301°T 289°T	15.13 km 11.75 km	Eleven pieces of mylonitized peridotite (1.2kg) similar to islet types; abundant mud and ooze.
AII20-45	Rock Dredge With Chain Bag and 10cm Pipe	3-24-66	On Off	0900 1148	3164 2487	132°T 131°T	9.82 km 6.92 km	Twenty-five pieces of mylonitized peridotite similar to islet types; few pieces with breccia "clots" on serpentine surface; 12kg mud and foraminiferal ooze.
AII20-46	Rock Dredge With Chain Bag and 10cm Pipe	3-24-66	On Off	1345 1630	3146 2542	183°T 179°T	10.70 km 7.72 km	Over 60kg of mylonitized peridotites similar to islet types; some greenish-gray clay (1kg); 2-3kg foraminiferal ooze.
AII20-47	Rock Dredge With Chain Bag and 10cm Pipe	3-25-66	On Off	0520 0830	3328 2487	036°T 042°T	16.90 km 14.48 km	Approximately 1.5kg foraminiferal ooze and mud.
AII20-48	Rock Dredge With Chain Bag and 10cm Pipe	3-25-66	On Off	1210 1330	2268 1646	076°T 072°T	11.99 km 12.39 km	Few small rock fragments, highly weathered; approximately 2kg rock gravel, clay and foraminiferal ooze; 2 gorgonians.

*Times given are those when the Dredge first reached and finally left bottom. Depths are those under the ship at those times, given in meters and corrected for the velocity of sound in water.

†Bearings and distances are ship ranges from Lighthouse Southwest Islet, based on radar fixes. Location beyond that range are given as latitude and longitude and are based on dead reckoning and celestial navigation.

Table 4: CORE LOCATIONS AND RESULTS ST. PAUL'S ROCKS REGION[§]

Number	Equipment	Date	Time*	Depth* (meters)	Bearing† Latitude	Distance† Longitude	Result
CH35-3	12m Piston Core + 1.5m Pilot Core	3-21-63	1900	4713	00°20.5'S	30°02'W	11.3m Core of interlayered calcareous oozes; some graded sand beds. 1m Pilot Core of Calcarious mud.
CH35-4	15m Piston Core + 1.5m Pilot Core	4-8-63	2003	4846	02°58'S	29°38'W	7.6m Core of mottled gray and brown mud. 92cm Pilot core of brown mud.
CH35-5	12m Piston Core + 1.5m Pilot Core	4-12-63	1145	4312	00°17'N	28°49'W	10.7m Core of interlayered clays and oozes; some graded sand beds. 23cm Pilot core of foram-rich mud.
CH35-6	12m Piston Core + 1.5m Pilot Core	4-15-63	0430	4563	00°41.5'S	33°36'W	10.1m Core of foram-rich mud; some graded sand beds. 78 cm Pilot core of foram-rich mud.
CH35-7	15m Piston Core + 1.5m Pilot Core	4-16-63	1915	4539	00°40'N	34°57'W	10.7m Core of mottled gray and brown mud; some foram sand layers. 76cm Pilot core of brown foram-rich mud.
AII20-13	3m "Dart" Core + 1.5m Pilot Core	3-18-66	0836	309	258°T	3.14 km	13cm Detrital rock fragments and foram-rich sediments. Foram sand and sponge in pilot core.
AII20-14	12m Piston Core + 1.5m Pilot Core	3-23-66	1000	3824	00°39.5'N	29°19.5'W	10.4m Core of foram-rich muds and sands. 59cm Pilot Core of foram-rich mud.
AII20-15	1.5 Free-Fall Core	3-24-66	2220	3462	00°40.7'N	29°18.5'W	84cm of foram-rich mud.
AII20-17	1.5 Free-Fall Core	3-24-66	2318	3290	340°T	13.36 km	62cm of foram-rich mud.

Table 4: (Continued)

Number	Equipment	Date	Time*	Depth* (meters)	Bearing† Latitude	Distance† Longitude	Result
AII20-19	1.5m Free-Fall Core	3-24-66	2337	2573	338°T	9.50 km	31 cm of foram-rich mud.

§ - Cores 3 to 7 taken during Cruise 35, R/V Chain, 1963; Cores 13 to 19 taken during Cruise 20, R/V Atlantis II, 1966.

* - Times are when core penetrated bottom; depths are those under the ship at time of penetration given in meters and corrected for the velocity of sound in water.

† - Bearings and distances are ship radar ranging or compass sighting on lighthouse. Southwest Islet; for locations outside this range, positions are given as latitude and longitude based on celestial navigation and dead reckoning.

Table 5: RELATIVE PROPORTION (PERCENT) OF ROCK TYPES IN REGION OF ST. PAUL'S ROCKS

Dredge Number	Basalt	Meta-basalt	Peridotite	Serpentinite	Gabbro	Con-solidated Ooze	Uncon-solidated Ooze
AII20-24						75	25
25				5			95
26			70			5	25
27			75	15			10
28			100				
29			100				
30			100				
31			100				
35						10	90
36	75		5			5	15
37			100				
38			100				
39	25	10	5		2		58
40			40	40			10
41			100				
42	5	5				50	40
43	20		30	5			45
44			40				60
45			20	10			70
46			90				10
47							100
48							100
CH35- 7			100				
15			100				
16			100				
17			100				
18			100				

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2. R/V CHAIN Cruise 35
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